STEEL RAILS and IRON HORSES

Science and Technology Transform a Continent

On May 10, 1869, a golden spike driven into a wooden crosstie completed an iron road linking the Atlantic and Pacific coasts of North America. A century later, on July 20, 1969, Americans Neil Armstrong and Edwin Aldrin, Jr., became the first humans to walk on the moon. From rails to space travel, the application of new technologies has enabled us to explore places once considered unreachable.

This article explores early railroad expansion in this country and the ways new railroad technologies contributed to the development of the United States, particularly the western states. The activities presented will help students understand how a steam engine works and why stopping a train can be a lengthy proposition. Students will also learn why magnets will figure prominently in future trains, why train derailments can be caused by hot weather, and why, as legend holds, train robbers put their ears to the track to detect oncoming trains. (This practice is not recommended[!], but substitute activities are included.)

Linking these scientific concepts is the story of the "Iron Horse" and the people who devoted their lives to its success.

By [illegible] Varna, Richard Brook, and Elizabeth Bieben

Utah State Historical Society

Work trains such as these would carry equipment and supplies to the end of the tracks.

CADASTRAL SURVEY

Unlike surveys of the East based on such natural features as mountain ridges or rivers, surveys of the unsettled West marked boundaries neatly and systematically into townships composed of 36 1.6-km (one-mile)-square sections. This geometric survey work is known as "cadastral" surveying. Federal surveyors began this task more than 200 years ago, and today the Bureau of Land Management's cadastral surveyors continue to mark and resurvey public land boundaries throughout the United States.

Since the federal government granted every other section of land along the right-of-way to the railroads, a checkerboard land-ownership pattern emerged and still exists today in many areas of the Midwest and West. This intermingling of publicly and privately owned lands poses unique challenges to land managers. Because natural ecological systems do not follow this rigid grid, public land managers must work with neighboring land owners and together consider the impacts of land management decisions on the larger area. (For a detailed description of ecological considerations in public land management, see "Understanding Ecosystem Management" in the November/December 1994 issue of *Science and Children.*)

Union Pacific Museum Collection

This map of land grants to the Union Pacific Railroad shows the checkerboard land-ownership pattern characteristic of the midwestern and western states.

America Embraces the Railroads

The development of railroad technology, which had begun in England, advanced rapidly in the United States. Whereas European railroads connected existing cities separated by relatively short distances, American lines reaching to the West had to find their own way through vast tracts of land. The railroads made settlement of these lands by Americans and European immigrants possible on an unprecedented scale. Agricultural and mining interests, for example, suddenly had easy access to an expanded range of markets that increased the value of their products. In addition, government subsidies to the railroads provided lands that were used to attract even more settlers; in fact, the railroads actively recruited immigrants from Europe. The railroads strongly influenced where people would settle, laying down track and then establishing towns along the route.

Railroads and Land Resources

Railroad construction required huge initial investments of capital that were beyond the means of the infant industry. To provide the railroads with a source of cash and to promote western expansion and settlement, the U.S. government offered grants of federal lands. At first, these grants went only to the states in which the lines were built, but later they went directly to the railroads.

The grants consisted of a given number of alternating one-mile-square sections on each side of the right-of-way, which resulted in the familiar checkerboard land-ownership pattern of the West. The General Land Office, predecessor of today's Bureau of Land Management, oversaw the process. By the time Congress stopped issuing such grants in 1871, some 80 railroads had received title to more than 50 million hectares of federal land (about twice the size of Colorado), 90 percent of it west of the Mississippi. Money from these grants allowed the railroads to expand westward.

The railroads also had a defining influence over the development and use of the nation's natural resources. The harvesting of timber and the extraction of

minerals, especially coal, was—and still is—heavily dependent on the railroads. Ranchers and farmers needed the railroad to transport their cattle and grain to markets. And the routes the early steam engines took were selected based in part on the availability of water, wood, coal, and other resources that might be needed along the way. Early railroad tracks themselves were laid on wooden ties that were hand hewn by the millions from logs cut from forests in the vicinity.

The Transcontinental Railroad

By the mid-1840s, America had become a two-ocean nation. As a result of the 1848 Treaty of Guadalupe Hidalgo with Mexico and the earlier settlement of the Oregon question with Great Britain, the United States now had control over California, Oregon, and much of the interior of the continent. Recognizing the need to connect the vast area, in 1853 the Congress charged Jefferson Davis, then Secretary of War, to conduct feasibility surveys for a transcontinental railroad. After years of debate on the best route, President Lincoln signed the Pacific Railroad Act on July 1, 1862, and one of the greatest adventures in American history began.

Two railroad companies, the Union Pacific and the Central Pacific, were authorized to construct a railroad and telegraph line that would span a continent. The Union Pacific was to build westward from the 100th meridian (near Omaha, Nebraska) across the Great Plains, and the Central Pacific was to build eastward from Sacramento through the Sierra Nevada.

In addition to the land grants, the government promised funds to each of the railroads depending on how much track was laid, touching off a fierce competition between the two. Soon the silent lands that had been the province of nomadic Native Americans, fur traders, and explorers gave way to the bustle of surveyors, graders, trestle builders, tunnel blasters, and spikers. Thousands of workers, including Civil War veterans and immigrants, were enlisted to do the back-breaking work of laying track across the treeless deserts and through towering granite mountains. As the tracks from the Central Pacific and Union Pacific approached each other, the two railroads could not agree on a meeting

California State Railroad Museum

Chinese workers on the Central Pacific Railroad in California. The Chinese, at first considered too small to do the backbreaking labor of laying track, made a great contribution toward completing the transcontinental railroad. Many workers were killed in blasting accidents or died from exposure during the harsh winters in the Sierra Nevada.

A MODERN CHALLENGE: SURVEYING THE ALASKA RAILROAD

When Alaska became a U.S. Territory in 1912, there was a need to connect parts of the expansive area. In contrast to the private development of the railroads in the lower 48 states, the federal government took charge of developing the Alaska Railroad, which connects Seward, Anchorage, Fairbanks, and Whittier. In 1985, Congress transferred control of this railroad to the State of Alaska. To complete the transfer, a comprehensive land survey was undertaken by the Bureau of Land Management's cadastral surveyors. Now nearing completion, the survey has covered 880 kilometers. Surveyors worked with railroad personnel to assure their safety and to coordinate their work with the trains' schedules. Because of weather conditions, surveyors could work on-site only five months of the year. It took survey crews almost seven years to complete the field work. Without the use of such technology as Doppler satellite receivers and inertial guidance systems, the job would have taken even longer.

Ed Bovy

This historic train relic can be found near Nome, Alaska. Railroads provided a critical transportation and communication link between Alaskans and the outside world.

FOCUS ON SAFETY: ALWAYS EXPECT A TRAIN

Almost every injury caused by trains could have been prevented, according to the Federal Railroad Administration (FRA). Most victims (in the past 10 years, 800 children killed, 2,500 seriously injured) ignore warning signs or signals or play illegally on trains or tracks. The FRA offers the following safety tips:

1 Never walk or play on railroad tracks. 2 Do not play on or in railroad cars. 3 Stay out of railroad yards. They are dangerous places. 4 Stay off railroad bridges and out of railroad tunnels. 5 Always look both ways and listen before crossing railroad tracks at railroad crossings. 6 Never cross tracks when warning lights are blinking or safety gates are down. 7 Never try to race or play chicken with a train. 8 When riding your bike, obey all signs and signals at highway-railroad intersections. 9 Play it safe: Always expect a train.

In order to emphasize just how dangerous trains can be, have your class consider the braking distances of different types of trains.

- A 150-car freight train traveling at 48 km/h (30 mph) takes 1.05 km (two-thirds of a mile) to stop.
- A 150-car freight train traveling at 80 km/h (50 mph) takes 2.4 km (1.5 miles) to stop.
- An eight-car passenger train traveling at 96 km/h (60 mph) takes 1.05 km (two-thirds of a mile) to stop.
- An eight-car passenger train traveling at 126 km/h (79 mph) takes 1.8 km (1 and 1/8 miles) to stop.

always expect a train

Douglas County Museum Photograph

This view of railroad logging in Oregon illustrates the melding of steam and railroad technologies in providing development of forest products in the late nineteenth and early twentieth century.

point; as a result, they surveyed and graded a parallel roadbed 320 kilometers long. Finally, on May 10, 1869, a telegraph key clattered out a message from Promontory, Utah, where the two tracks met, indicating the line's completion.

During the next two decades, railroads experienced their greatest growth, adding 176,000 kilometers to the system and eventually constructing seven transcontinental rail routes. By the eve of the First World War, railroads had reached their peak in America, with over 400,000 kilometers of track.

From Steam to MagLev

Today, new technology has resulted in faster, more efficient trains that consume less energy than ever before. For almost 150 years, locomotives burned wood, coal, or oil to create steam. The steam was then injected into cylinders to create pressure to drive the pistons; the spent steam was exhausted upwards through the stack and also created a draft to bring oxygen into the firebox. Steam-powered locomotives required massive amounts of water and fuel–either coal or wood—consuming four times as much water as fuel.

As the railroads began searching for an alternative to the steam locomotive at the turn of the century, they turned to electrical power. Electric locomotives were clean (important because of new air pollution ordinances) and powerful. These trains could convert electrical energy from an outside power source directly into mechanical energy, resulting in smooth torque, almost instantaneous, unlimited power (important for climbing hills), and eliminating the need to carry fuel on board.

In Montana and Washington, cheap hydroelectric power made it possible for railroads such as the Chicago, Milwaukee, St. Paul, and Pacific Railroad—also known as the Milwaukee Road—to electrify close to 950 kilometers of track by 1916. Eventually, however, the high start-up construction and maintenance costs made early long distance electric trains impractical.

In 1892, German engineer Rudolph Diesel patented a new type of engine that could be used to power a locomotive. Instead of relying on coal or wood to produce steam, the diesel engine relies on petroleum-based fuel ignited under compression. The vaporized fuel is injected into compressed, high-temperature air and ignited in a combustion chamber to drive pistons in the cylinders. Energy is then transmitted to generators that make electricity to power the electric

motors that turn the wheels. Compared to steam locomotives, diesel-electric trains consume less fuel, produce less pollution, require less maintenance, and can stay in service longer each day. Several diesel locomotives linked together can be operated by a single engineer, unlike the steam engine, which requires at least two men to a unit. The first successful diesel-electric locomotive was introduced in 1925 by the Central Railroad of New Jersey. Today, nearly all trains operating in the United States are powered by diesel engines.

One of the most exciting recent innovations in railroad technology is magnetic levitation, or Maglev, which relies on the principles of magnetism—attraction and repulsion. This new technology, still under development, will result in trains that are faster, more efficient, more comfortable, and more environmentally sound. No longer will trains rumble heavily along steel rails; rather, they will float along on a magnetic cushion without any direct contact with the ground.

From the cumbersome coal- and wood-powered steam engines to the emerging technologies of Maglev, railroads have become faster and more energy efficient. But at the same time, the world's demand for energy continues to grow. Just as railroad technology helped shape the development of the United States one hundred years ago, the development of new transportation technologies will influence the way we wrestle with environmental challenges in the future. Studying the evolution of railroad technology not only gives students a feel for how a vast landscape was settled and developed, but also illustrates the important relationship between technology, society, and our environment.

COLORADO HISTORICAL SOCIETY

A steam engine on the Florence and Cripple Creek Railroad in Colorado. Today, this area is part of the Gold Belt Loop, a back country byway on public land that allows visitors to drive on parts of the old railbeds.

UTAH STATE HISTORICAL SOCIETY

A locomotive ("Gold Run") and roundhouse outside Terrace, Utah.

DID YOU KNOW. . . ?

- The average freight train hauls 1,515 metric tons of freight in about 70 cars.
- The United States maintains the greatest amount of railroad track, approximately 315,200 kilometers. Russia has 126,400 kilometers of track, the second greatest number. There are about 1,216,000 kilometers of track worldwide.
- On June 6, 1833, Andrew Jackson became the first President of the United States to ride a train. (It was on the Baltimore and Ohio Railroad.)
- The first locomotive built for sale in America was the Best Friend of Charleston, constructed in 1830. It cost $4,000.
- Standard Time was created in 1883 to keep train schedules. Previously, clock readings varied as much as 30 minutes between cities in the same state.
- Sixty percent of the coal that produces the majority of the nation's electricity is shipped by rail. Two-thirds of all new car shipments are made by rail.
- Fuel efficiency of trains has increased by more than half since 1980.
- Nearly every 90 minutes, someone in the United States is hit by a train.
- A four-unit diesel locomotive weighing 675 metric tons is supported on 78 meters of track composed of 10.4 metric tons of steel rail held in place by 270 kilograms of spikes resting on 2.8 metric tons of steel tie plates, resting on 15 metric tons of treated wood crossties, resting on 117 metric tons of crushed rock ballast.

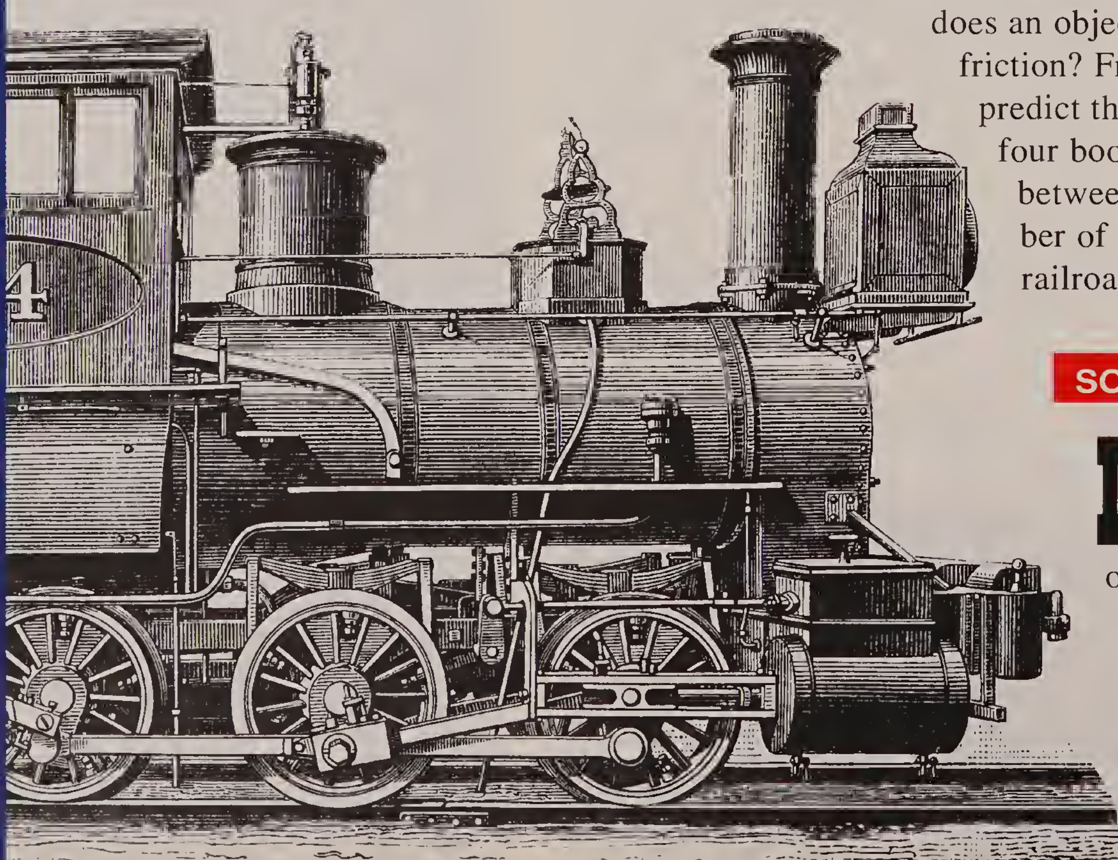
FOR THE CLASSROOM

BUILD A STEAM ENGINE

The following is a simple exercise that demonstrates how steam can be harnessed to create mechanical energy. (For a more detailed look at how a steam engine operates, refer to the back of the accompanying foldout.)

A steam engine converts heat energy into mechanical energy. When water is heated, it becomes water vapor, and its volume increases about 1,600 times. The increased volume of water vapor produces a force that is used to operate a mechanical structure. Such engines once ran most trains, ships, factories, and some cars.

In about A.D. 60, a man named Hero used wood to boil water, and he proceeded to use steam from the boiling water to power an engine. Students can create their own version of Hero's engine by using a small, metal spice can with a press-on metal lid, a nail, a hammer, water, string, a hot plate, and a ring stand. First, near the top of the can, use the hammer and nail to carefully punch two holes on opposite sides of the can. Pour about 10 mL of water into the can. Next, place the string under the lid and attach the lid to the can so that equal lengths of string come out of each side. Hang the can from a ring stand, making sure that it hangs without twisting. Place the hot plate under the can. Make sure not to touch the can. Ask students to describe what happens after the water begins to boil and produce steam. How would they describe the motion of the can? (The can begins to rotate.)



MASS AFFECTS FRICTION

Today, trains pull more massive loads than ever before. Although improved design has reduced friction over the years, additional mass continues to increase both the friction on the tracks and the amount of energy required to pull the train. To help students understand how mass affects friction, obtain four textbooks, a one-meter piece of string, and a spring scale. Follow this procedure:

- Use the spring scale to measure the mass of one book. Record the figure.
- Tie the string to make a large loop. Place the loop of string inside the front cover of the book. Hook the spring scale to the other end of the loop.
- Drag the book across a level surface by pulling on the spring scale at a steady speed. Record the force of friction as shown on the spring scale.
- Use the spring scale to measure the mass of the second book. Add the second book's mass to the first book's mass and record.
- Next, place the second book on top of the first book and with the spring scale, drag both books across a level surface, again recording the force of friction.
- Repeat the process, adding the third and fourth books.

What happens to the force needed to pull the books as the number of books increases? How does an object's mass affect the force of friction? From a graph of the data, can you predict the force needed to pull more than four books? Can you draw an analogy between books and trains, and the number of locomotives needed to pull more railroad cars?

SOUND CONDUCTORS

In old movies and cartoons, train robbers sometimes place their ear on a railroad track to check for an oncoming train. Students can learn why this method works by exploring how sound travels at different speeds in different media.

Use a metal coat hanger, a one-meter-long piece of string,

and a one-meter-long piece of thin-guage copper wire. First, tie the middle of the string around the hook of the hanger. Wrap one end of the string around your left index finger and the other end of the string around your right index finger. Then, gently tap the hanger against a table. Listen for the sound it makes. Next, with the string still wrapped around your fingers, put your fingers in your ears and tap the hanger again. What do you notice about the sound? Repeat the steps, this time using the wire. Which is the better conductor, the string or the wire? (The wire is better.) Why? (Sound travels faster through the wire than through the string.) For a simpler demonstration, lay an ear on a wooden table as someone taps it. Then rest your head on your arm and listen for the tapping. You can also put a pillow between your ear and the table.

As an extension, research whether certain materials conduct sound better than others. (The speed of sound is dependent on temperature and the medium through which the sound travels. In solids, atoms are usually closer together, which is why solids transmit sound faster than air does.)

THE DOPPLER EFFECT

At one time or another, most people have observed a train's horn getting higher in pitch as it approaches and then lower as it moves away. This phenomenon is referred to as the Doppler effect. To people on the train, the horn would seem to have the same pitch at all times. How can two people listening to the same horn hear different notes? (The motion of the train as it moves toward you causes the waves to be emitted closer together.) To demonstrate this phenomenon, have students stand in the center of a hallway. Starting at the end of the hallway, walk toward the students while blowing a whistle or ringing a bell. Continue walking past the students to the other end of the hall. Discuss the change in pitch. (The sound of the bell or whistle becomes higher as the source of the sound comes closer to the student.)

Have students research the practical applications of the Doppler effect. (Most radar depends on the Doppler effect to locate and determine the speed of objects. The police use Doppler radar to identify speeding motorists.) As an extension, invite a local weatherman to discuss how Doppler radar is used to forecast weather, or have a land surveyor talk to the class about how Doppler satellite receivers have been used to determine geographic positions in remote areas.

HEAT AFFECTS THE TRACKS

Periodically, one will read in newspapers about train derailments resulting from the thermal expansion of metal tracks. Ask students if they have ever run hot water over a jar's metal lid because it was too tightly closed to open. Why does this help? (Because the metal expands under the heat of the water, just as train tracks can expand in high temperatures.)

Expansion must be taken into consideration when designing railroads, highways and bridges. Have students research the measures that engineers employ to prevent concrete roads from cracking or buckling, and trains from derailing. (For example, concrete highways and bridges are built with expansion joints to allow for the expansion and contraction of the construction materials.)

ENERGY CONSERVATION

Studying trains is a good way to study different types of engines and the evolution of energy efficiency through the years. The earliest locomotives, powered by wood and coal, were highly inefficient because much energy was converted into thermal energy that escaped into the atmosphere. An engine is energy efficient when it minimizes the loss of useful energy. Have students learn about the energy sources and workings of different types of train locomotives and answer the following questions:

- How would friction affect the energy efficiency of a train? (Friction transforms useful energy into thermal energy.)
- How expensive are the energy sources for different trains? Which is the most expensive? The least? (Electric trains tend to be more expensive than diesel trains. Maglev trains will be cheap to power, but they are expensive to develop and set up.)
- Is the energy source renewable? (Wood, for example, is a renewable resource; coal is not.)
- Does the energy source create pollution or involve safety risks? If so, how can these effects be minimized?

FOR THE CLASSROOM

ENERGY TRANSFORMATION

Energy can be transformed from one form to another. Forms of energy include electric, radiant, chemical, mechanical, and nuclear energy. Have students create a simple energy flow diagram for different locomotives (steam, diesel, electric, and Maglev). For example, a steam engine burns coal or wood to transform chemical energy into thermal energy. The thermal energy heats water to create steam. The steam creates mechanical energy to move the train.

As an extension, have students create simple toys that use conversion of energy to create motion. They may use wheels, rubber bands, propellers, and dowels. Have students explain the transformations of energy that occur. This would include the energy they use to push or pull the toys, as well as energy released from the unwinding of rubber bands and so on.

About the Authors

Carl Barna, historian, and Richard Brook, archaeologist, are actively involved with the Bureau of Land Management's cultural resources programs. Elizabeth Rieben is an education specialist with the BLM's Office of Environmental Education.

Cover Photograph

Replica of the first steam engines Jupiter and No. 119 on the transcontinental railroad. Photograph courtesy of the Utah State Historical Society.

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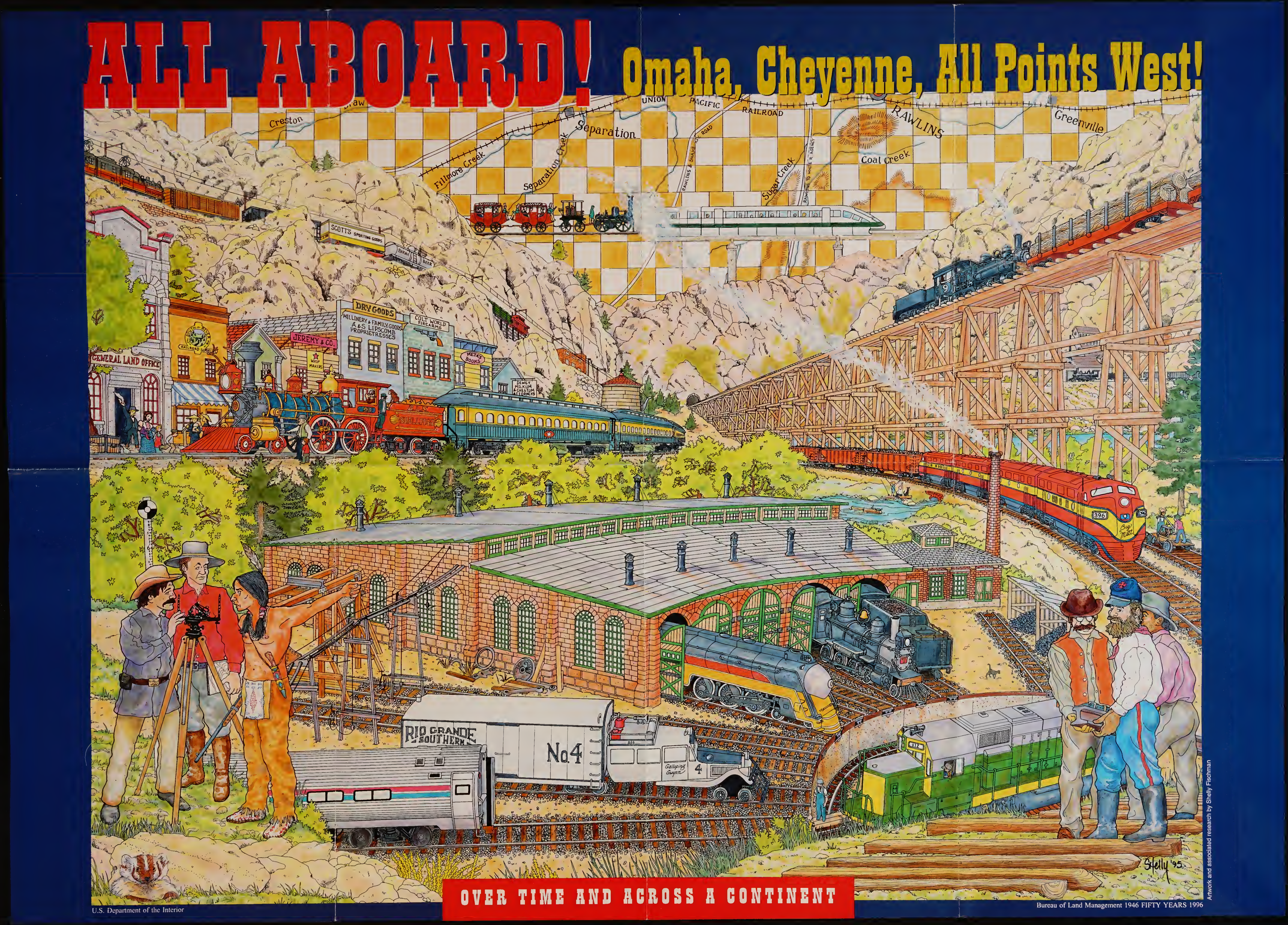
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Omaha, Cheyenne, All Points West!
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DRY GOODS
MILLINERY & FAMILY GOODS
A & S LIPSCOMB PROPRIETRESSES
COLT WORLD FIREARMS
JEREMY & CO.
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RIO GRANDE SOUTHERN
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OVER TIME AND ACROSS A CONTINENT
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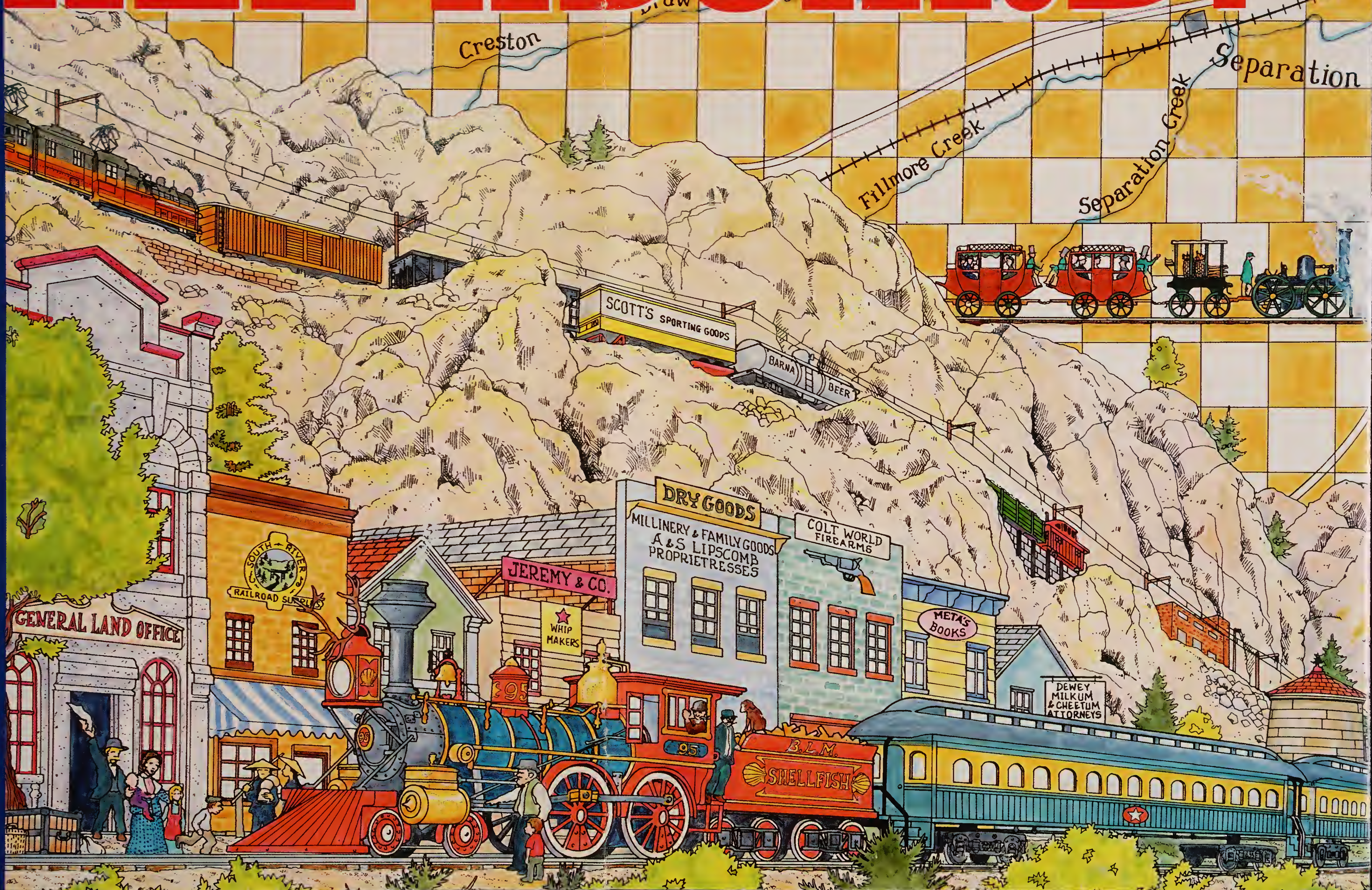
ALL ABOARD!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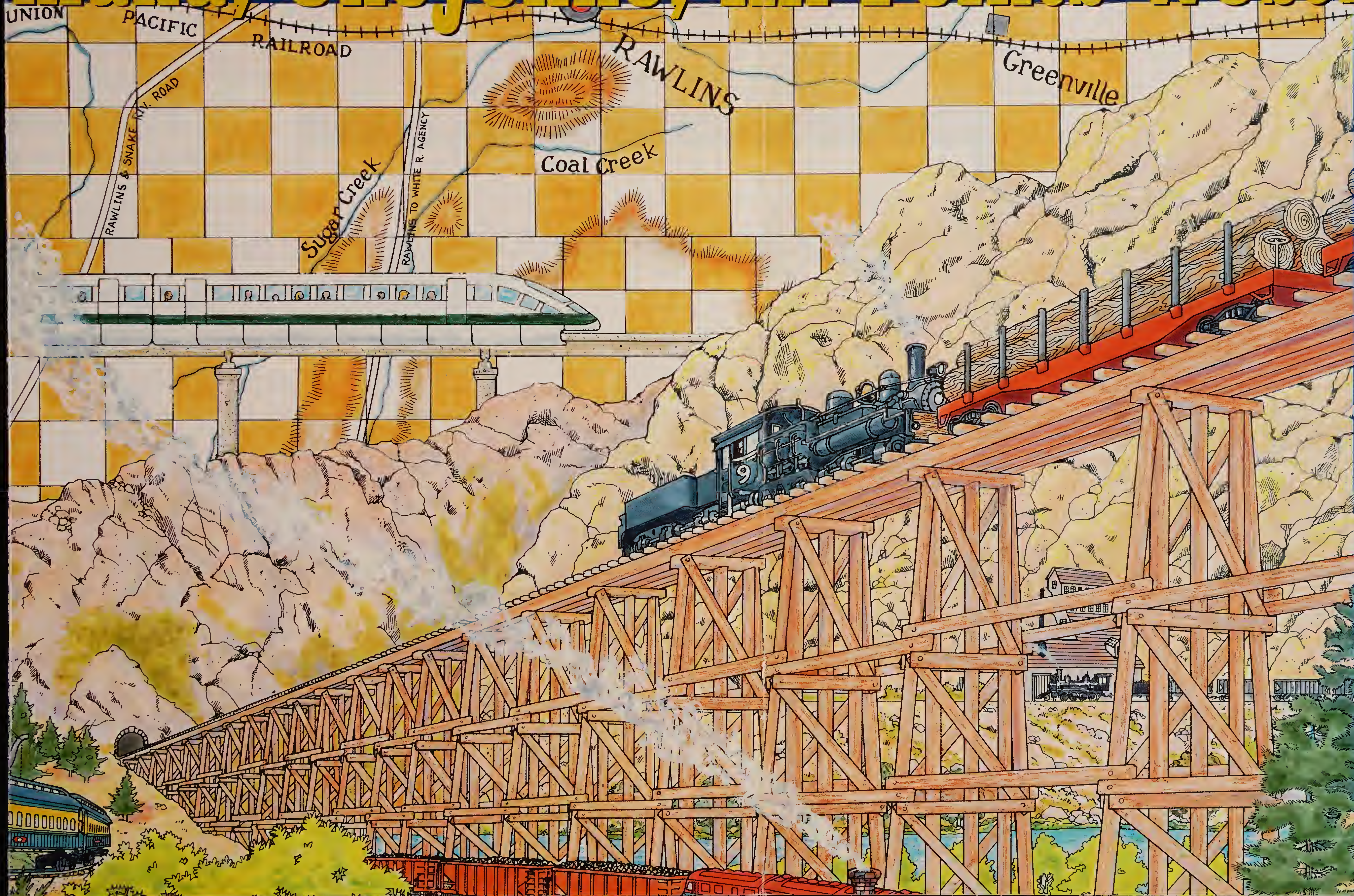

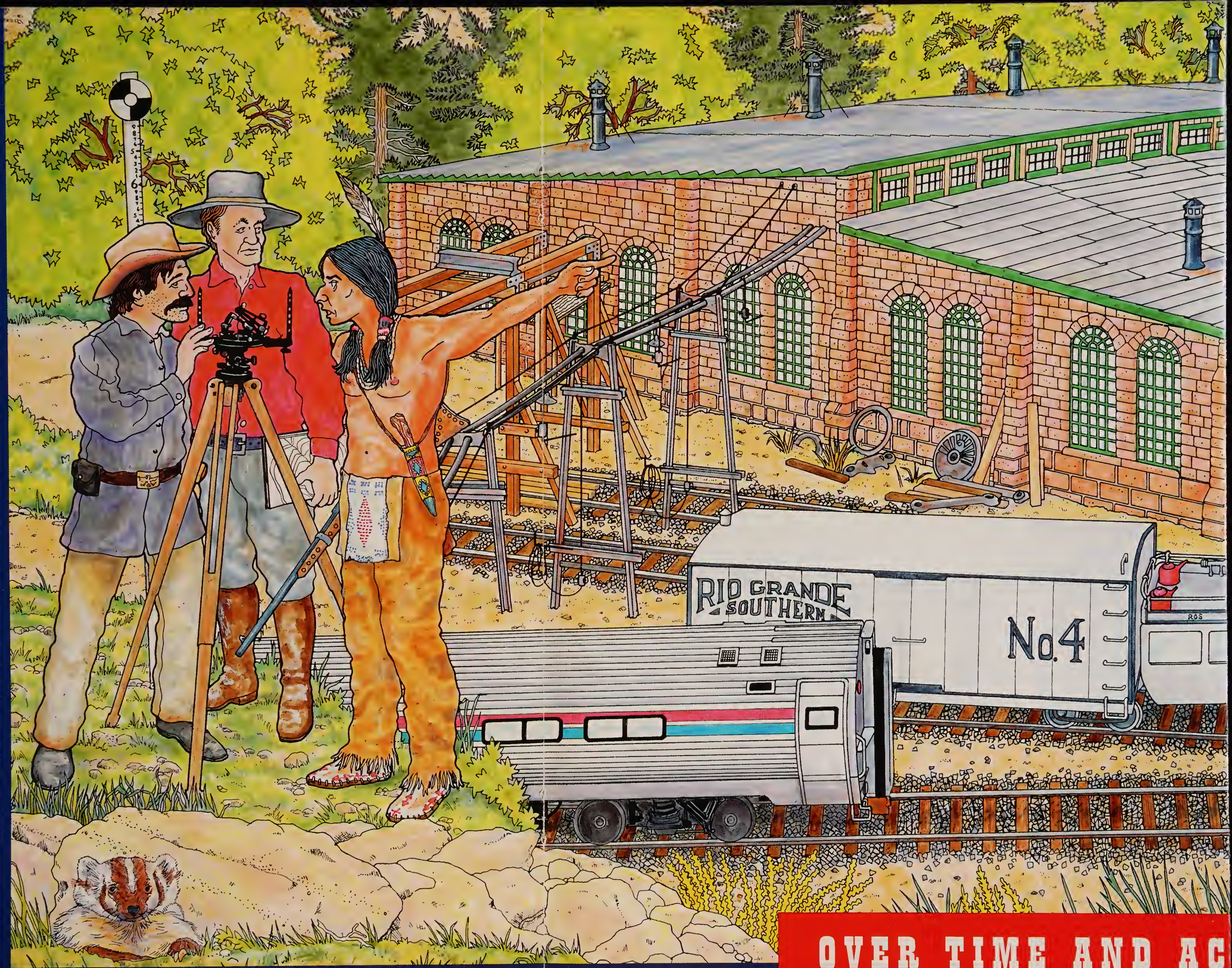

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ON TRACK WITH SCIENCE

ASSOCIATION OF AMERICAN RAILROADS

U.S. Department of Transportation
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Full Steam Ahead!

How to build a miniature steam engine.

By Steve Newman

This hands-on activity involves building a steam generator system to power a single-piston engine. Because of safety concerns, the generator provides only a very low pressure ("head of steam") and the movement of the piston only approximates that of a piston driven with controlled, regulated, high-pressure steam. Students will learn about the basic components of a steam engine and will understand the need for early train engineers to have dependable fuel and water resources along the railroad right-of-way. Many early railroad outposts served as woodcutting camps and watering or coaling stations, and often were located near river crossings or springs. In many ways, the history of settlement and growth in the western states is linked to servicing the steam-powered "Iron Horse."

The following steam engine construction project involves four stages. First, it requires construction of three principle components: the firebox, the boiler, and the engine. This stage is followed by discussion and analysis and a safety readiness review to prepare students for the final stage: operating the engine.

Materials

The materials for this project can be purchased at your local building supply store for less than $15. You will need

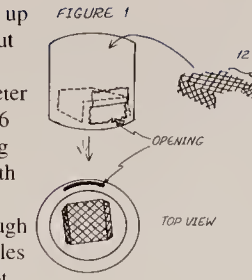
- one unused, gallon-size, metal paint can with lid (if you can find only a used can, make sure it contained latex paint, and clean it thoroughly with soap and water);
- one unused, quart-size, metal paint can with lid (for used cans, apply the same requirements as noted above);
- six meters soft copper tubing, $^1/_4$ inch in diameter;
- one roll of metallic tape;
- two wine corks;
- one circular metallic electrical junction box (used by electricians to connect wires at light fixtures or other junctions);
- one standard electrical cable clamp compatible with the junction box;
- 15 centimeters copper pipe, $^1/_2$ inch in diameter;
- one 12 x 24-centimeter section of mesh screen, such as the type used for rain-gutter leaf guards;
- 35 centimeters hard plastic tubing, $^1/_8$–$^1/_4$ inch in diameter;
- two hose clamps, $^1/_2$–$1^1/_4$ inch;
- charcoal pieces;
- one lightweight wooden skewer (as for barbecuing), about 20 centimeters long;
- a dowel rod 1.5 centimeters long and $^3/_8$ inch in diameter;
- a screwdriver;
- a $^1/_2$-inch-diameter drill (machine bit);
- tin snips;
- pliers;
- hammer;
- and scissors.

Stage One: Assembly

This engine can be assembled with relative ease if you have access to common shop tools. You may choose to pre-assemble the engine at home; to have the school maintenance professional assemble it at school; or to have properly equipped and trained students assemble it over a single class period. For this task, you must exercise caution, common sense, and every safety precaution possible. In the case of students' assembling the engine, a safety planning session must be incorporated into the program to identify potential hazards associated with the use of shop tools and the handling of sharp objects. For each potential hazard identified, students should identify a risk-reduction measure. The process of analyzing hazards and identifying risk-reduction measures is an enjoyable, common-sense discipline applicable to this project just as it is when NASA engineers prepare to launch the space shuttle. (The following step-by-step instructions are appropriate for an adult; if students are involved in the construction, you will need to take additional safety measures.)

Firebox: To make the firebox, take a permanent marker and draw a 15 x 5-cm rectangle on the outside of the gallon-size can close to the base. With a machine bit, drill a series of holes along the base of the rectangle. Using tin snips, cut through the can between the drilled holes. Then, cut through the can along the two sides of the rectangle. Be careful of the sharp edges. With pliers, pull up and fold against the can's side the flap of metal you've cut out, leaving a 15 x 5-cm opening in the can.

FIGURE 1



Next, cut a piece of mesh screen into a 12 x 24-centimeter rectangle. On the 24-cm side, bend down approximately 6 cm on each end. Then, insert the mesh "platform," resting on the bent edges, into the can, lining the platform up with the opening in the can. (See Figure 1.)

Next, drill holes about one centimeter in diameter through the can's lid along half of the outside perimeter; these holes will provide ventilation for the firebox. The coals will not burn unless they have an adequate supply of oxygen flowing into the firebox flap cut-out and up through these holes.

To make the firebox coil, take soft copper tubing and measure 30 cm from one end. Starting at the 30-cm mark, wind the copper tubing to create five coils, each 12 cm in diameter. Then, wind the remaining tubing to create about 15 coils, each with a diameter of about 8 cm. Make sure that about 20 cm of tubing is left; take that end of the tubing and thread it through one of the end ventilation holes in the lid. Thread the 30 cm of tubing extending from the bottom of the coils through the other end ventilation hole. (See Figure 2.)

FIGURE 2

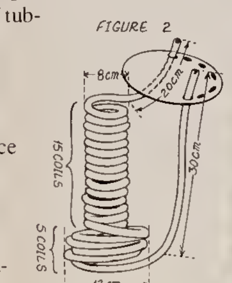
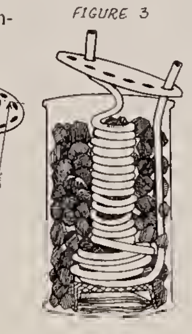


FIGURE 3



Next, insert the coil in the paint can, resting it on the mesh platform. Fill the space outside and inside the coil with charcoal pieces. Secure the lid. (See Figure 3.)

Boiler: Construct the boiler from the quart-size paint can. In the center of the can's lid, drill a hole about one centimeter in diameter. Then drill two 1-cm holes through one side of the can, one near the base and the other above it, near the top. (See Figure 4.) Using a length of copper tubing that extends from the firebox, bore holes through the centers of the two corks. Be patient, it takes a few minutes. Then, cut two lengths of hard plastic tubing, one piece 25 cm long, the other 10 cm long. Insert the lengths of plastic tubing into the corks so that they fit snugly and protrude slightly at the other ends of the corks. Insert the cork with the longer piece of tubing into the bottom hole and the other cork into the top hole in the side of the boiler can. Secure the hose clamps over the outside ends of the corks. (See Figure 5.)

FIGURE 4

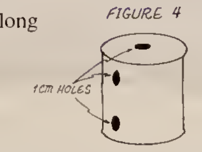
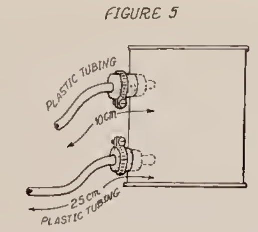


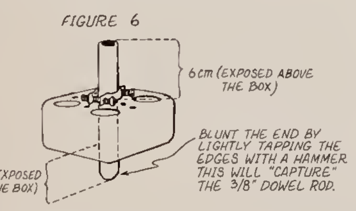
FIGURE 5



Next, place the boiler can on top of the firebox can, with the corks facing away from the firebox ventilation holes. Using metallic tape, join and secure the plastic tubing that extends from the bottom cork to the copper tubing that extends from the bottom of the coil. Then join the plastic tubing that extends from the top cork to the copper tubing that extends from the top of the coil, again securing the joint with tape.

Engine: Using a hammer and screwdriver, tap on the center hole of the junction box and remove. Secure the cable clamp to the junction box with the retaining ring on the inside. Next, insert 15 cm of copper pipe through the cable clamp connector. Adjust the length so that the copper pipe will project a few centimeters through the hole in the junction box. Use a hammer to blunt inward the edges of the copper pipe end that projects into the boiler. This will keep the "piston" from falling in the boiler. (See Figure 6.)

FIGURE 6



To construct the piston, insert one end of the skewer into the side of the 1.5-cm length of dowel rod (the "piston head"). Place this skewer piston inside the copper pipe. You might also try using a pipe cleaner or plastic drinking straw as the piston. To emphasize the piston's movement, attach a paper flag to the top of the skewer. (See Figure 7.)

Stage Two: Discussion and Analysis

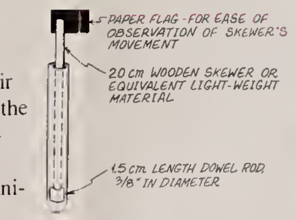


FIGURE 7

Discuss with students the engine's components, their functions, and how they were assembled. Also, track the energy flow that will occur when the engine is operational (the conversion of the chemical energy of the charcoal to the heat energy of the steam to the mechanical energy of the moving piston). Encourage students to think about the way that steam engines rely on two natural resources—coal and water. Discuss the energy-efficiency of modern trains, both diesel-electric and Maglev. Finally, conduct a brainstorming session to identify potential hazards associated with the operation of the model steam engine. Involve students in identifying appropriate risk-reduction measures and form a student safety team to enforce safety procedures.

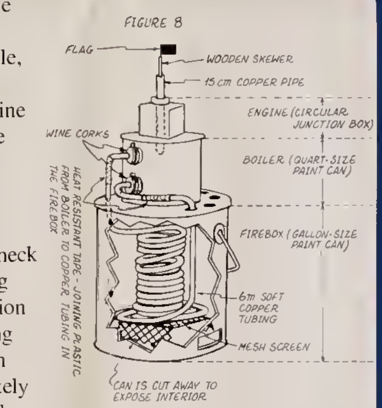
Stage Three: Preparing for Operation

The steam engine should be **operated outdoors only** (because carbon monoxide is released when charcoal briquets are burned) **by the teacher**. Because it will take 20–30 minutes to heat the coals and water sufficiently to generate the hot steam needed to move the piston, you may wish to enlist the assistance of parent volunteers or teacher's aids to ignite the coals in advance.

To ensure that the project is fun and safe, carefully observe the following guidelines during this phase of the activity:

- Conduct an "operational readiness check." Review potential hazards and the safety measures to be used. Make sure members of the safety team know their assignments.
- Using red cones or a rope, define a "warning ring" on the ground around the steam engine and instruct students not to step inside it (have several adults monitor this). Explain to students that both paint cans, other parts of the engine, and the steam will be very hot. Note: For safety reasons, this engine has been designed to produce very low pressure steam.
- Have available potholders or hot gloves for handling the steam engine.
- Remove any flammable materials from inside the warning ring.
- Place the boiler on a paving stone, ceramic tile, or other non-flammable surface.
- Place a bucket of water next to the steam engine (this will be used to douse the engine after the demonstration is completed).

FIGURE 8



Stage Four: Operation

First, fill the boiler can two-thirds full of water. Check connectors for leaks. Secure the boiler lid by tapping gently with a hammer around the edges of the junction box. (See Figure 8.) Next, ignite the coals by lighting pieces of crumpled newsprint and then feeding them into the firebox opening (let one piece burn completely before feeding the next). The coals will be ready in less than 30 minutes. (You can accelerate the heating of the coals using a hair dryer or bellows to increase ventilation through the firebox.)

Finally, you will need to adjust the piston. Because the steam buildup is unregulated, the actions of the piston will occur at intervals. As the piston lifts up, steam will leak around it and allow gravity to pull the piston back down. The piston's weight and the available pressure will determine the piston's action. Adjust the piston's weight (by trimming the skewer) as needed to keep it moving smoothly.

Through this hands-on experiment, students will learn how a steam engine operates and observe the conversion of the fossil fuel's potential energy into the piston's mechanical energy. Follow up with a visit to your local train museum so that children can see exactly how the steam-powered piston makes the train's wheels turn.

Steve Newman is an engineer for NASA and co-chair of the Taylor Elementary After-School Hands-on Science Program in Arlington, Virginia.

BLM

Transcontinental Railroad Back Country Byway

The last 144 kilometers of track laid by the Central Pacific Railroad crews before meeting the Union Pacific at Promontory, Utah, are now the Transcontinental Railroad Back Country Byway. Although the rails and towns are gone, the landscape along the railroad grade looks much the same today as it did in 1869. Located on public lands, the byway is open to vehicles and hikers and includes 30 interpretive sites along the way. Also nearby is the Golden Spike National Historic Site.

UNION PACIFIC MUSEUM COLLECTION: A.C. HULL

Benton, Wyoming

Construction camps and end-of-track towns were often lawless sinks of crime. One such place was Benton, Wyoming, on the Union Pacific Railroad. In the summer of 1869, Benton served as home to more than 3,000 people. Fine alkali dust coated the streets and the wind seemingly never stopped. Water had to be hauled from the Platte River and could be sold for a dollar a barrel. Twice a day, trains arrived from the East bringing passengers and freight which then had to be unloaded and shipped further West in stagecoach or wagons. Despite its isolation, Benton did have a newspaper, and in 1868 Ulysses S. Grant treated the folks to a speech during his Presidential campaign. Like many railroad towns, Benton exists no more, but its remnants can be seen on public lands in central Wyoming near Rawlins.

BLM

Hideout at Hole in the Wall

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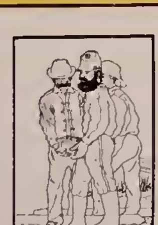
The train-robbery trend was short-lived, however, as new technology resulted in faster and more efficient trains that became too difficult to stop or catch.

RUSS ELAM

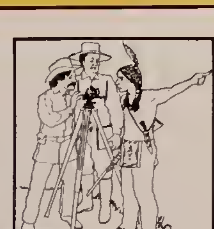
Rails to Trails

Throughout the country, abandoned rail corridors are being converted to trails for recreational use through a national non-profit program called "Rails to Trails." Over 7,200 kilometers have been converted to trails and parks under this program. One example is the Bizz Johnson Trail on public lands in California. Where steam engines once hauled logs to local mills and lumber products to distant markets, now bicyclists, hikers, horseback riders, joggers, and skiers explore the scenic Susan River Canyon. *Note: Rails to Trails areas do not contain actual railroad track. Old tracks and ties are removed for salvage. It is not safe to assume that any track still intact is abandoned.*

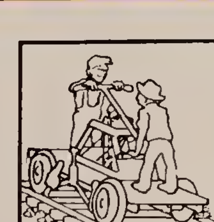
Key to Poster Front



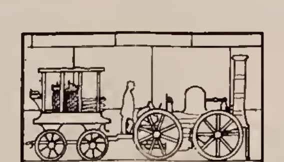
Gandy Dancers: As railroads were built, the ringing of hammers on spikes created a symphony of sound. Using Gandy Manufacturing Company tools, construction workers coordinated their dangerous work so smoothly that to observers it seemed like a dance.



Surveyors: Before railroads could be built, the best and least costly routes had to be determined. Surveyors were the pathfinders whose tools have evolved from the relatively simple solar compass and stadia rods of the nineteenth century to the laser transits and global positioning satellites of today.

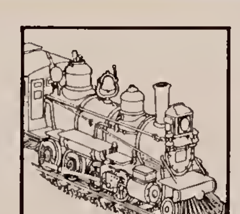


Handcar: This simple machine, which operates on the principle of the lever, enables railroad inspection and maintenance crews to move short distances along rail lines easily and inexpensively.

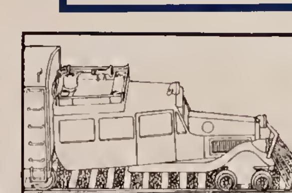


1831 Train: In the 1830s, America's first trains ran on iron-surfaced wooden rails. Passengers rode on modified highway stagecoaches and were subject to showers of sparks, while locomotive crews had no protection from the elements.

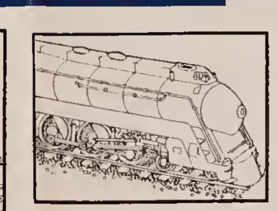
Jupiter: In the early days of railroading, locomotives were given fanciful names and were often quite colorful. The balloon stack on this mid-nineteenth century wood-burning locomotive contained sets of baffles or screens that trapped sparks that could set grass or trees on fire.



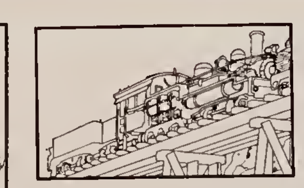
RPG 7: This consolidation-type locomotive served as the typical passenger and freight locomotive of the late nineteenth and early twentieth century.



Goose: During the 1930s, railroads suffered severe economic losses due to declining passenger and freight traffic. One line, the Rio Grande Southern, adjusted to this decline by combining an automotive body with a baggage compartment to carry both passengers and freight. These colorful and unique machines were nicknamed "Galloping Geese" because of the sound of their air horns.



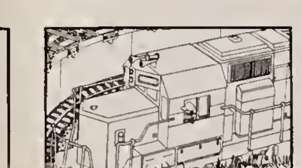
Bullet: During the 1930s and 1940s, railroad owners tried to present a progressive image and improve locomotive efficiency. A streamlined design presented a more modern appearance and decreased friction.



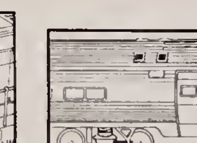
Shay: Railroads that were used to harvest timber required special locomotives to operate in rugged country over rough tracks. One such locomotive was called a "shay," after its inventor Ephraim Shay. Each set of trucks, which contained the driving wheels, could swivel independently of the other, and each was directly linked by gears to the power transmission line shown along the side for maximum pulling power.

Electric: Electricity held much promise as an efficient, clean, and inexpensive power source for locomotives. Rather than carry their own fuel supplies, these locomotives could draw power from outside sources, such as the overhead wires shown. High initial costs incurred in constructing such lines limited their wider development.

F9: In the 1930s, diesel-electric engines such as this were among the revolutions in railroad technology. By reducing operating and maintenance costs, and by making more power economically available to move heavier trains, they spelled doom for the steam locomotive.



Engine on Turntable: Powerful engines like that pictured here form the backbone of today's railroads. Steam engines and early diesels could only operate safely in one direction and had to be turned on a rotating table like the one shown.



Passenger Car: A typical passenger car of today.

Maglev: Like their pioneering forefathers, tomorrow's railroaders will explore new applications of science and technology for moving trains faster, more safely, and more efficiently. Experimental trains like the Maglev will reach speeds in excess of 500 km/h, take up less land space, and reduce pollution by moving railroads away from hydrocarbon-based fuels.

SCIENCE & CHILDREN

ASSOCIATION OF AMERICAN RAILROADS

U.S. Department of Transportation

Federal Railroad Administration

ON TRACK W

Full Stea

How to build a mini

By Steve

BLM

Transcontinental Railroad Back Country Byway

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Union Pacific Museum Collection; A.C. Hull

This hands-on activity involves building a steam generator system to power a single-piston engine. Because of safety concerns, the generator provides only a very low pressure ("head of steam") and the movement of the piston only approximates that of a piston driven with controlled, regulated, high-pressure steam. Students will learn about the basic components of a steam engine and will understand the need for early train engineers to have dependable fuel and water resources along the railroad right-of-way. Many early railroad outposts served as woodcutting camps and watering or coaling stations, and often were located near river crossings or springs. In many ways, the history of settlement and growth in the western states is linked to servicing the steam-powered "Iron Horse."

The following steam engine construction project involves four stages. First, it requires construction of three principle components: the firebox, the boiler, and the engine. This stage is followed by discussion and analysis and a safety readiness review to prepare students for the final stage: operating the engine.

Materials

The materials for this project can be purchased at your local building supply store for less than $15. You will need

- one unused, gallon-size, metal paint can with lid (if you can find only a used can, make sure it contained latex paint, and clean it thoroughly with soap and water);
- one unused, quart-size, metal paint can with lid (for used cans, apply the same requirements as noted above);
- six meters soft copper tubing, $^1/_4$ inch in diameter;
- one roll of metallic tape;
- two wine corks;
- mesh screen, such as the type used for rain-gutter leaf guards;
- 35 centimeters hard plastic tubing, $^1/_8$–$^1/_4$ inch in diameter;
- two hose clamps, $^1/_2$–$1^1/_4$ inch;
- charcoal pieces;
- one lightweight wooden skewer (as for barbecuing), about 20 centimeters long;
- a dowel rod 1.5 centimeters long and $^3/_8$ inch in diameter;
- a screwdriver;

rectangle. Be careful of the sharp edges. W
and fold against the can's side the flap of m
out, leaving a 15 x 5-cm opening in the can

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rectangle. On the 24-cm side, bend down a
cm on each end. Then, insert the mesh "pla
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FIGURE 4

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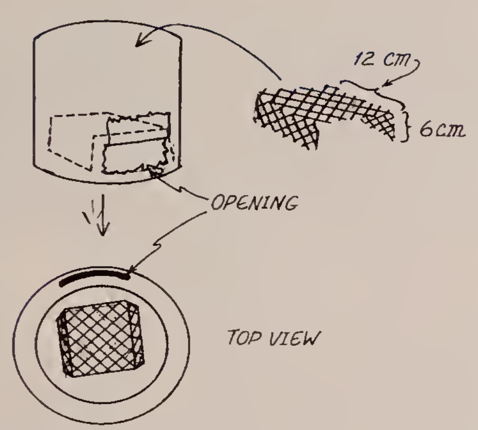


FIGURE 2

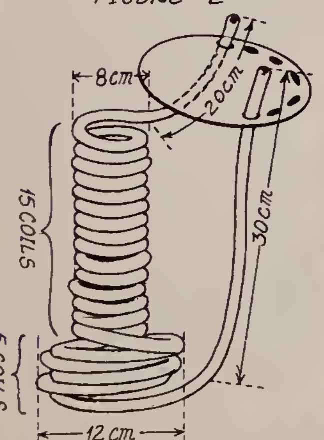
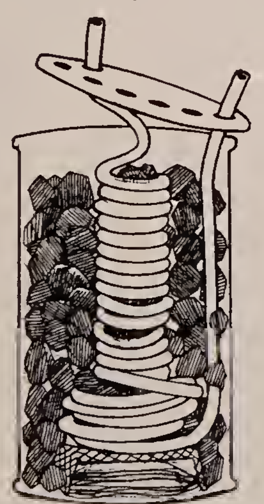


FIGURE 3



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near the top. (See Figure 4.) Using a length

Stage Two: Discussion and Analysis

Discuss with students the engine's components, their functions, and how they were assembled. Also, track the energy flow that will occur when the engine is operational (the conversion of the chemical energy of the charcoal to the heat energy of the steam to the mechanical energy of the moving piston). Encourage students to think about the way that steam engines rely on two natural resources—coal and water. Discuss the energy-efficiency of modern trains, both diesel-electric and Maglev. Finally, conduct a brainstorming session to identify potential hazards associated with the operation of the model steam engine. Involve students in identifying appropriate risk-reduction measures and form a student safety team to enforce safety procedures.

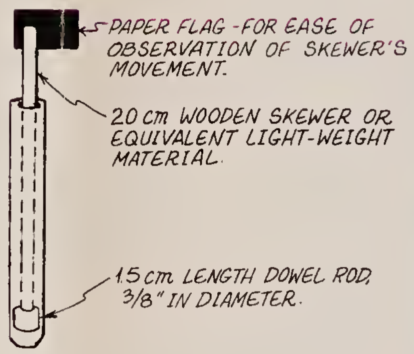

FIGURE 7

Stage Three: Preparing for Operation

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BLM

Hideout at Hole in the Wall

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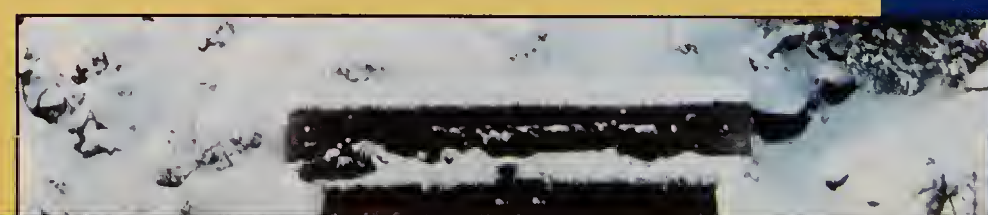
Russ Elam



Benton, Wyoming

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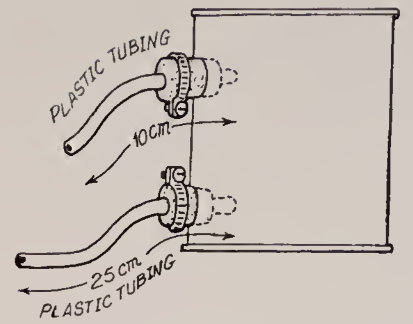
- one circular metallic electrical junction box (used by electricians to connect wires at light fixtures or other junctions);
- one standard electrical cable clamp compatible with the junction box;
- 15 centimeters copper pipe, 1/2 inch in diameter;
- one 12 x 24-centimeter section of
- a 1/2-inch-diameter drill (machine bit);
- tin snips;
- pliers;
- hammer;
- and scissors.

Stage One: Assembly

This engine can be assembled with relative ease if you have access to common shop tools. You may choose to pre-assemble the engine at home; to have the school maintenance professional assemble it at school; or to have properly equipped and trained students assemble it over a single class period. For this task, you must exercise caution, common sense, and every safety precaution possible. In the case of students' assembling the engine, a safety planning session must be incorporated into the program to identify potential hazards associated with the use of shop tools and the handling of sharp objects. For each potential hazard identified, students should identify a risk-reduction measure. The process of analyzing hazards and identifying risk-reduction measures is an enjoyable, common-sense discipline applicable to this project just as it is when NASA engineers prepare to launch the space shuttle. (The following step-by-step instructions are appropriate for an adult; if students are involved in the construction, you will need to take additional safety measures.)

Firebox: To make the firebox, take a permanent marker and draw a 15 x 5-cm rectangle on the outside of the gallon-size can close to the base. With a machine bit, drill a series of holes along the base of the rectangle. Using tin snips, cut through the can between the drilled holes. Then, cut through the can along the two sides of the

FIGURE 5



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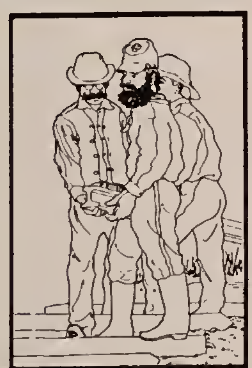
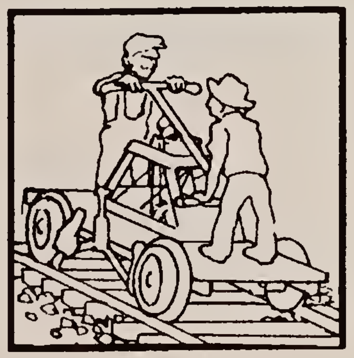
To construct the piston, insert one end of the skewer into the side of the 1.5-cm le Place this skewer piston inside the copper p cleaner or plastic drinking straw as the pist attach a paper flag to the top of the skewer.

Key to Poste

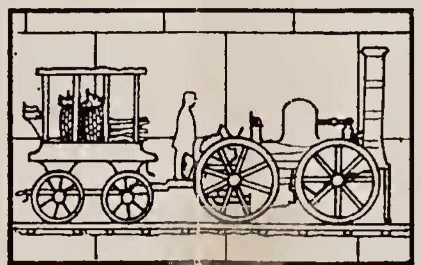


Gandy Dancers: As railroads were built, the ringing of hammers on spikes created a symphony of sound. Using Gandy Manufacturing Company tools, construction workers coordinated their dangerous work so smoothly that to observers it seemed like a dance.

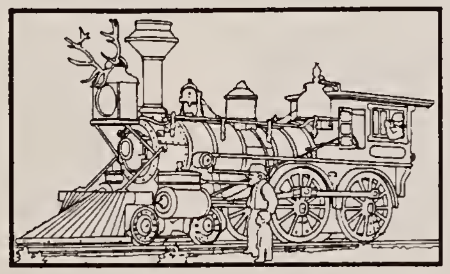
Surveyors: Before railroads could be built, the best and least costly routes had to be determined. Surveyors were the pathfinders whose tools have evolved from the relatively simple solar compass and stadia rods of the nineteenth century to the laser transits and global positioning satellites of today.



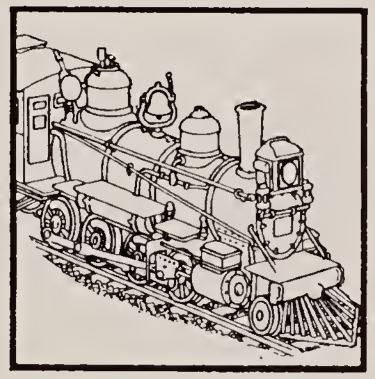
Handcar: This simple machine, which operates on the principle of the lever, enables railroad inspection and maintenance crews to move short distances along rail lines easily and inexpensively.



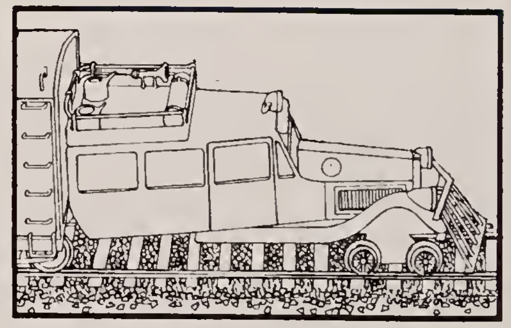
1831 Train: In the 1830s, America's first trains ran on iron-surfaced wooden rails. Passengers rode on modified highway stagecoaches and were subject to showers of sparks, while locomotive crews had no protection from the elements.



Jupiter: In the early days of railroading, locomotives were given fanciful names and were often quite colorful. The balloon stack on this mid-nineteenth century wood-burning locomotive contained sets of baffles or screens that trapped sparks that could set grass or trees on fire.



RPG 7: This consolidation-type locomotive served as the typical passenger and freight locomotive of the late nineteenth and early twentieth century.



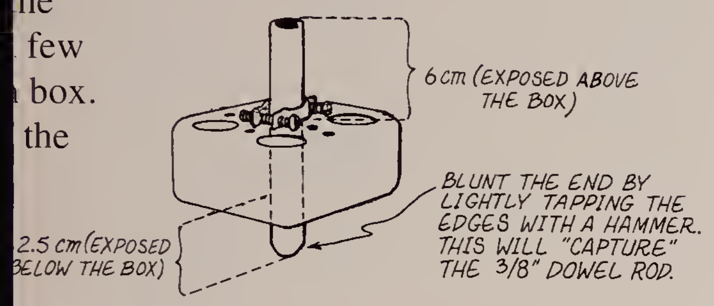
Goose: During the 1930s, railroads suffered severe economic losses due to declining passenger and freight traffic. One line, the Rio Grande Southern, adjusted to this decline by combining an automotive body with a baggage compartment to carry both passengers and freight. These colorful and unique machines were nicknamed "Galloping Geese" because of the sound of their air horns.

firebox, bore holes through the centers of
v minutes. Then, cut two lengths of hard
long, the other 10 cm long. Insert the
corks so that they fit snugly and protrude
corks. Insert the cork with the longer piece
nd the other cork into the top hole in the
e hose clamps over the outside ends of the

top of the firebox can, with the corks fac-
ilation holes. Using metallic tape, join and
tends from the bottom cork to the copper
ttom of the coil. Then join the plastic tub-
er tubing that extends from the top of the

, tap on the center hole of the junction
the junction box with the retaining ring
pipe
he
few
box.
the

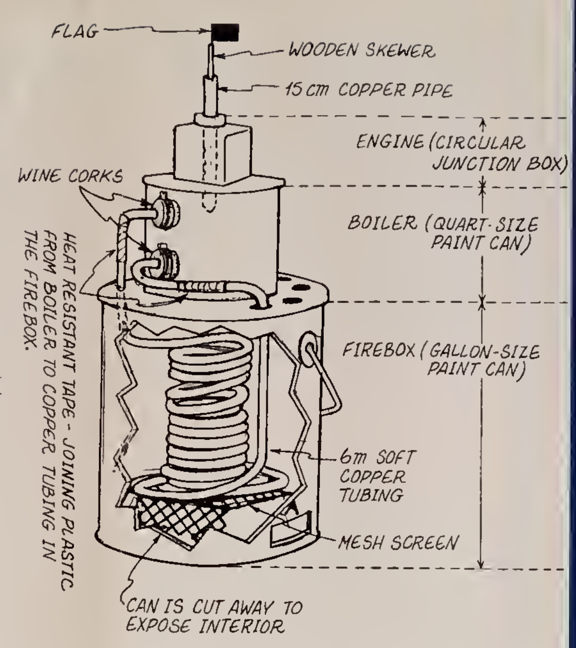
FIGURE 6



ngth of dowel rod (the "piston head").
pipe. You might also try using a pipe
n. To emphasize the piston's movement,
(See Figure 7.)

- Remove any flammable materials from inside the warning ring.
- Place the boiler on a paving stone, ceramic tile, or other non-flammable surface.
- Place a bucket of water next to the steam engine (this will be used to douse the engine after the demonstration is completed).

FIGURE 8



Stage Four: Operation

First, fill the boiler can two-thirds full of water. Check connectors for leaks. Secure the boiler lid by tapping gently with a hammer around the edges of the junction box. (See Figure 8.) Next, ignite the coals by lighting pieces of crumpled newsprint and then feeding them into the firebox opening (let one piece burn completely before feeding the next). The coals will be ready in less than 30 minutes. (You can accelerate the heating of the coals using a hair dryer or bellows to increase ventilation through the firebox.)

Finally, you will need to adjust the piston. Because the steam buildup is unregulated, the actions of the piston will occur at intervals. As the piston lifts up, steam will leak around it and allow gravity to pull the piston back down. The piston's weight and the available pressure will determine the piston's action. Adjust the piston's weight (by trimming the skewer) as needed to keep it moving smoothly.

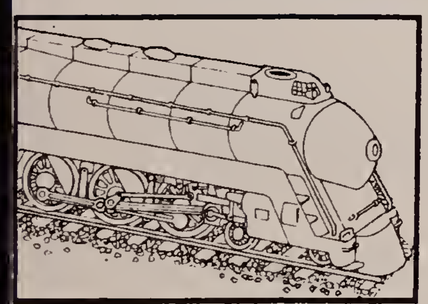
Through this hands-on experiment, students will learn how a steam engine operates and observe the conversion of the fossil fuel's potential energy into the piston's mechanical energy. Follow up with a visit to your local train museum so that children can see exactly how the steam-powered piston makes the train's wheels turn.

Steve Newman is an engineer for NASA and co-chair of the Taylor Elementary After-School Hands-on Science Program in Arlington, Virginia.

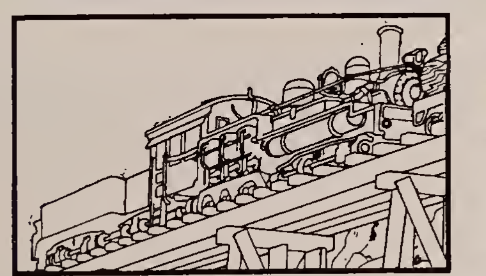
Rails to Trails

Throughout the country, abandoned rail corridors are being converted to trails for recreational use through a national nonprofit program called "Rails to Trails." Over 7,200 kilometers have been converted to trails and parks under this program. One example is the Bizz Johnson Trail on public lands in California. Where steam engines once hauled logs to local mills and lumber products to distant markets, now bicyclists, hikers, horseback riders, joggers, and skiers explore the scenic Susan River Canyon. *Note: Rails to Trails areas do not contain actual railroad track. Old tracks and ties are removed for salvage. It is not safe to assume that any track still intact is abandoned.*

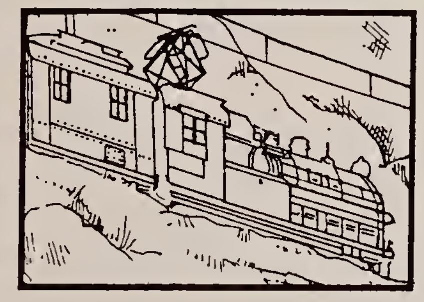
er Front



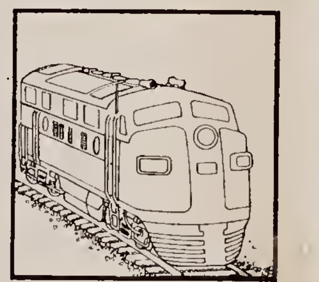
Bullet: During the 1930s and 1940s, railroad owners tried to present a progressive image and improve locomotive efficiency. A streamlined design presented a more modern appearance and decreased friction.



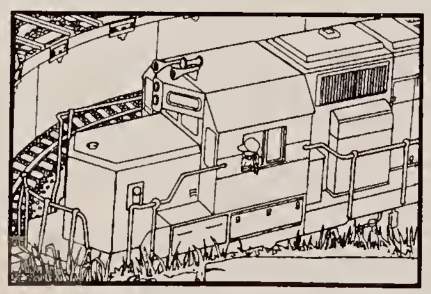
Shay: Railroads that were used to harvest timber required special locomotives to operate in rugged country over rough tracks. One such locomotive was called a "shay," after its inventor Ephraim Shay. Each set of trucks, which contained the driving wheels, could swivel independently of the other, and each was directly linked by gears to the power transmission line shown along the side for maximum pulling power.



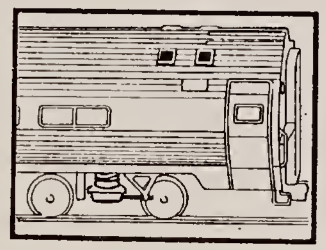
Electric: Electricity held much promise as an efficient, clean, and inexpensive power source for locomotives. Rather than carry their own fuel supplies, these locomotives could draw power from outside sources, such as the overhead wires shown. High initial costs incurred in constructing such lines limited their wider development.



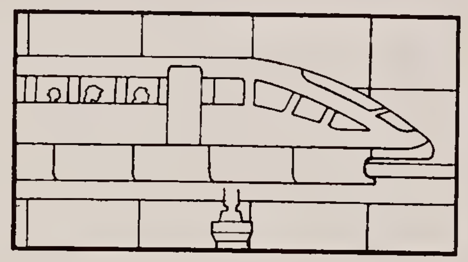
F9: In the 1930s, diesel-electric engines such as this were among the revolutions in railroad technology. By reducing operating and maintenance costs, and by making more power economically available to move heavier trains, they spelled doom for the steam locomotive.



Engine on Turntable: Powerful engines like that pictured here form the backbone of today's railroads. Steam engines and early diesels could only operate safely in one direction and had to be turned on a rotating table like the one shown.



Passenger Car: A typical passenger car of today.



Maglev: Like their pioneering forefathers, tomorrow's railroaders will explore new applications of science and technology for moving trains faster, more safely, and more efficiently. Experimental trains like the Maglev will reach speeds in excess of 500 km/h, take up less land space, and reduce pollution by moving railroads away from hydrocarbon-based fuels.